Review on Exergy and Energy Analysis of Solar Air Heater

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ABSTRACT

Solar air heater (SAH), which is the most essential component of solar drying systems, receive solar energy and convert it into thermal energy. This review presents descriptions and previous works conducted on performances analysis of SAHs. Exergoenviroeconomic, exergoenvironmental, environmental, and exergy analyses are also presented. In addition, results on the performances of SAHs are summarized. The exergy and energy efficiencies of SAHs at laboratorium testing range from 8% to 61% and from 30% to 79%, respectively.

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1. INTRODUCTION

Today the world is mainly facing two problems. One is the power crisis that is fast depleting of fossil fuels and other one is pollution problem like global warming and carbon emission. The best solution for this problem is utilization of renewable energy resources. In recent years, considerable importance has been given to the rational use of energy resources. The depletion of conventional energy resources and its adverse effect on the environment have revived the interest in renewable energy resource utilization [1]-[6]. As a result, various research and development (R&D) activities have been conducted to identify reliable and economically feasible alternative sources of clean energy. The choices include solar, wind, wave, and geothermal energies. Among these energy types, solar energy, which is widely used in heating and cooling applications, is the popular source because of the following characteristics: easy and direct to use, continuous, even quality, safe, free, environment-friendly, and monopoly-free [7]-[12].

Thermodynamics plays an important role in the energy efficiency of the system. The energy used in the system is significant and represents an often-reducible element of process cost. Potential savings can be obtained through exergy analysis via the identification of operational conditions. Exergy analysis is a useful method of establishing the design and operational strategies of many industrial processes, where the optimal use of energy is considered an important issue. This information is essential in the determination of plant and operational costs, energy conservation, fuel versatility, and pollutants. In recent years, exergy analysis has been widely utilized in the performance evaluation of thermal systems. Exergy can be termed as the maximum work produced by a system that goes through irreversible process from the original state of the system to the same system state as the environment. Therefore, the second Thermodynamic Law may also be written as exchanged exchanges for an inverted energy. Exergy analysis facilitates the determination of the maximum work produced by a material relative to the state of the material. For maximum work determination, comparisons are relative to those with non-state ability or zero capability to do, for example, a

system that is in a state of balance and cannot go through the energy conversion process to produce work. In this review, we focused on the energy and exergy analyses of flat plate SAHs [13]-[16].

2. TYPES OF SOLAR AIR HEATERS

SAH is one of the most significant parts of a solar thermal technology. It is a device designed to receive solar energy, convert it into thermal energy, and transfer the thermal energy to the fluid that flows into the collector. Figure 1A presents a conventional SAH consisting of a transparent cover, absorber, insulation, and frame. Accordingly, SAH consists of one or more glass sheets or a transparent material placed above an absorbing plate with air flowing around it. Conventional SAHs have low thermal efficiency. Thus, one way to enhance the collector's efficiency is to use heat transfer area through absorber with slats, box-type absorber, compound honeycomb, matrix-type absorber, corrugated surfaces (Figs. 1B and 1C), finned absorber (Figure 1D) and porous media (Figure 1E) [17]-[21].

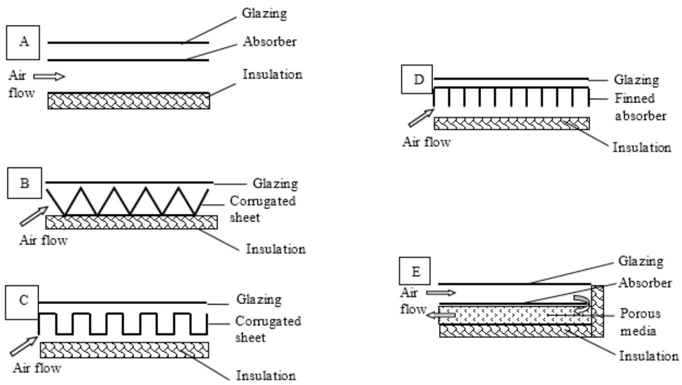

Figure 1. Various Types of Flat-Plate SAHs

3. PERFORMANCE ANALYSES OF SOLAR AIR HEATER

3.1. Energy and Exergy Analyses

The useful energy gained from the collector is calculated using solar radiation magnitudes. The thermal efficiency of a SAH is expressed as [17]-[21]:

$$\eta_c = \frac{Q}{A_c S} = \frac{\dot{m}C(T_o - T_i)}{A_c S} \tag{1}$$

Where is the collector efficiency (%), Q is the energy gained from the collector (W), C is the specific heat of air (J/kg °C), is the mass flow rate (kg/s), To is the outlet air temperature (°C), Ti is the inlet air temperature (°C), Ac is the collector area (m^2) and S is the solar radiation intensity (W/m^2).

Exergy is defined as the maximum amount of work that can be produced by a stream of matter, heat, or work as it reaches equilibrium with a reference environment. In the past few decades, exergy analysis has become an essential tool in thermal system design, analysis, and optimization [22] [23]. If the effects of kinetic and potential energy changes are neglected, then the general exergy balance rate can be expressed in the following rate form:

$$\sum \dot{E}x_i - \sum \dot{E}x_o = \sum \dot{E}x_d \tag{2}$$

where exergy destruction ($\dot{E}x_d$) or irreversibility may be expressed as

$$\dot{E}x_d = T_a \dot{S}_{gen}. \tag{3}$$

The entropy generation rate ($\dot{S}_{gen}$) may be expressed as

$$\dot{S}_{gen} = \left(\frac{1}{T_a} - \frac{1}{T_s}\right)\dot{Q}_s + \left[\ln\left(\frac{T_o}{T_i}\right) - \frac{T_o}{T_a} + \frac{T_i}{T_a}\right]\dot{m}C \cdot \quad (4)$$

The exergy efficiency is calculated as

$$\eta_{ex} = 1 - \frac{T_a S_{gen}}{\left[1 - \left(\frac{T_a}{T_s}\right)\right]\dot{Q}_s}, \quad (5)$$

where T_a is the ambient temperature and T_s is the solar temperature, and $\dot{Q}_s$ is the solar energy absorbed by the collector absorber surface, which is evaluated by the expression

$$\dot{Q}_s = I(\tau\alpha)A_c \cdot \quad (6)$$

The exergy efficiency of a process or system is maximized when exergy loss (Ex_{loss}) is minimized. The concept of an exergetic "improvement potential" (IP) is useful to the efficient analysis of processes or systems. The IP of a system or process is given by the following [24]-[26]:

$$IP = (1 - \eta_{Ex})Ex_{loss}. \quad (7)$$

Exergy analysis can also be performed using the sustainability index. It can be calculated as [27]

$$SI = \frac{1}{1 - \eta_{Ex}} \quad (8)$$

Tables 1 and 2 summarizes the studies conducted on energy and exergy analyses as reported by different researchers. Specifically, Table 1 presents the studies conducted on energy analysis of SAHs. Table 2 shows a comparison of the exergy analyses as reported by different researchers.

Table 1. The Studies Conducted on Energy analysis

Type of Solar Air Hather	Major Findings	References
Double-pass SAH with longitudinal fins	The thermal efficiency of this system was 30% to 60%.	Naphon [28]
Double-pass SAH with porous media	The thermal efficiency of this system was 60% to 70%.	Sopian et al. [29]
Advanced corrugated duct SAH	The optical efficiencies of this system was 37% to 56%.	Metwally et al. [30]
SAHs with internal and external recycles.	For downward-type SAHs with internal recycle the thermal efficiency was 62% at mass flow rate of 0.02 kg/s [31]. The effect of external recycle on the performance of SAHs with internal fins was investigated [32].	Yeh and Ho [31] [32]
Upward-type baffled SAHs	The thermal efficiency of this system was 68%. The effect of collector aspect ratio on the thermal efficiency of this systems was studied.	Yeh et al. [33]
Offset rectangular plate fin absorber plates	This SAH was exhibited up to 75% thermal efficiency in optimum conditions.	Ali [34]
Flat- and corrugated-plate SAHs	The results of simulations on heat exchange using six SAH models, both with and without tubes.	Dovic and Andrassy [35]
Double pass-flat and v-corrugated plate SAHs	The double-pass V-groove SAH was 11%–14% more efficient than the double-pass flat plate soalr air heater.	El-Sebaii et al. [36]
Flat plate, V-groove and finned SAHs	The V-corrugated absorber plate was 10%–15% and 5%–11% more efficient than the single-pass and the double-pass modes, respectively.	Karim and Hawlader [37]
SAHs with V-corrugated, fin, and absorber plates	The effect of the absorber shape factor change on collector performance was deduced for these SAHs.	Kabeel and Mejarik [38]
60º vee-corrugated SAHs with single glazing	The relative error from the evaluation of the top heat losses using the previous empirical relations for estimating the glass cover temperature.	Mahboub and Moummi [39]

Table 2. The Studies Conducted on Exergy Analysis

Type of Solar Air Hather	Major Findings	References
Double-pass SAH with and without fins.	The exergy efficiency of this SAHs was 6%–30% at Nusselt number of 5.42–36.34 and solar radiation of 425–790 W/m^2.	Fudholi et al. [40]
Finned double-pass SAH.	The exergy efficiency of this SAH was 15%–28% and improvement potential was 740–1070 W at solar radiation of 425–790 W/m^2.	Fudholi et al. [41]
New flat-plat SAH having different obstacles on absorber plates.	The thermal efficiency is significantly dependent on solar radiation, mass flow rate, and surface geometry.	Akpinar and Kocyigit [42]
SAHs with passive augmentation techniques.	The thermal efficiency increased 10%–30% using the passive techniques compared with that of the conventional SAH.	Ucar and Inalli [43]
Double-pass SAH having different obstacles on absorber plates.	The use of obstacles in this SAH was found to be an efficient method of adapting an air exchanger based on user needs.	Esen [44]
SAH having chamfered rib-groove roughness on absorber plate.	The entropy generation decreases with the increase in relative roughness height.	Layek et al. [45]
Different SAH configurations.	The graphs of the exergy flow rate as a function of mass flow rate for different collector configurations.	Torres-Reyes et al. [46]
Irreversible flat-plate SAHs.	A generalized methodology to determine the optimum path flow length of the working fluid by means of a thermohydraulic model that was developed	Torres-Reyes et al. [47]
Flat plate SAH.	The maximum exergy output was achieved at a low mass flow rate value if the air inlet temperature is low.	Gupta and Kaushik [48]
Various types of SAHs with different front absorption surfaces.	More of the significant parameters, such as collector efficiency, air temperature difference, and pressure loss, were found to decrease exergy loss.	Kurtbas and Durmus [49]
SAH having discrete V-down rib roughness on absorber plate.	The effects of the rib roughness parameters and the Reynolds number on exergy efficiency were studied.	Singh et al. [50]
V-corrugated SAH.	The effects of mass flow rate, aspect ratio, and inlet air temperature using various configurations with different artificial roughness were investigated.	Hedayatizadeh et al. [51]

3.2. Economic and Environment Analyses

Caliskan [27] studied the performance analyses of SAH. He concluded that SAH can be assessed more effectively using the exergy- and economy-based exergoenvironmental and exergoenviroeconomic analyses because they consider the environmental condition upon calculation. In addition to enviroeconomic and environmental analyses, the exergoenviroeconomic and exergoenvironmental analyses of SAHs are promising methodologies in terms of effectively assessing carbon pricing using enhanced thermodynamics and life cycle. Environmental analysis, enviroeconomic analysis, exergoenvironmental analysis, and exergoenviroeconomic analysis can be explained as follows [27]:

Environmental analysis can be calculated as

$$x_{CO_2} = y_{CO_2} \dot{E}n_{solar,in} t_{working} \tag{9}$$

Enviroeconomic analysis can be calculated as

$$C_{CO_2} = x_{CO_2} c_{CO_2} \tag{10}$$

Exergoenvironmental analysis can be calculated as

$$x_{ex,CO_2} = y_{CO_2} \dot{E}x_{solar,in} t_{working} \tag{11}$$

Exergoenviroeconomic analysis can be calculated as

$$C_{ex,CO_2} = x_{ex,CO_2} c_{CO_2} \tag{12}$$

where $\dot{E}n_{solar,in}$ is the energy rate of the solar energy option, $t_{working}$ is the working time of SAH, y_{CO_2} is the carbon dioxide (CO_2) value for the energy option defined by the life cycle assessment methodology, and x_{CO_2} is the released CO_2 in a considered time. c_{CO_2} and C_{CO_2} are the CO_2 emission price and enviroeconomic parameter, respectively. $\dot{E}x_{solar,in}$ is the exergy rate of the solar energy option, x_{ex,CO_2} is the

released CO_2 in the time considered given the exergetic values, and C_{ex,CO_2} is the exergetic price of CO_2 emission.

4. CONCLUSIONS

Table 3 and 4 summarizes the energy and exergy analyses as reported by different researchers. Based on the present review, the conclusions as follow:

- The energy efficiency of SAHs is strongly dependent on mass flow rate. Thus, increasing mass flow rate through the SAH results in higher efficiency.
- The exergy efficiency of SAHs is highly dependent on solar radiation.
- The energy and exergy efficiencies of the SAH range from 30% to 79% and 8% to 61%, respectively.

Table 3. Comparison of Energy Analysis

Type of SAHs	Energy efficiency	Optical efficiency	Ref.
6 conventional types		0.20 - 0.69	[52]
Double-pass SAH with fins	0.43 - 0.58		[53]
	0.34 - 0.62		[54]
	0.37 - 0.70		[55]
	0.04 - 0.72		[56]
	0.35 - 0.66		[57]
	0.54 - 0.79	0.71- 0.83	[40]
	0.30 - 0.60		[28]
Double-pass SAH with porous media	0.60 - 0.70		[29]
5 conventional types		0.37 – 0.56	[30]

Table 4. Comparison of exergy analysis

Type of SAHs	$\dot{E}x_i$ (W)	$\dot{E}x_o$ (W)	$\dot{E}x_d$ (W)	Ex_{loss} (W)	η_{ex} (%)	Ref.
Double-pass SAH with fins	1065-1979	163-535	902-1444		15.28-27.03	[41]
4 Types	19 - 181	3 - 30	11 - 151		8.32 – 44.00	[42]
5 Types	312 - 365	129 - 175	137 - 236	44 - 64	36 - 56	[43]
4 Types	300 - 390	100 - 189	121 - 290	39 - 74	25.65 – 60.97	[44]

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